OpenCMISS-iron examples and tests used by *OpenCMISS* developers at University of Stuttgart, Germany

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CONTENTS

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LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This document contains information about examples used for testing *OpenCMISS-iron*. Read: How-to[1] and [1].

1.1 Cmgui files for cmgui-2.9

1.2 Variations to consider

- Geometry and topology
  - 1D, 2D, 3D
  - Length, width, height
  - Number of elements
  - Interpolation order
  - Generated or user meshes
  - quad/hex or tri/tet meshes
- Initial conditions
- Load cases
  - Dirichlet BC
  - Neumann BC
  - Volume force
  - Mix of previous items
- Sources, sinks
- Time dependence
  - Static
  - Quasi-static
  - Dynamic
- Material laws
  - Linear
  - Nonlinear (Mooney-Rivlin, Neo-Hookean, Ogden, etc.)
  - Active (Stress, strain)
- Material parameters, anisotropy
- Solver
  - Direct
  - Iterative
- Test cases
  - Numerical reference data
  - Analytical solution
- A mix of previous items

1 https://bitbucket.org/hessenthaler/opencmiss-howto

1.3 Folder structure

TBD..

2 HOW TO WORK ON THIS DOCUMENT

In this section, indicate what you are working on or if a given example was finished

- no mark: to be done
- x: currently working on it
- xx: done

Initials	Full name
EA	Ekin Altan
CB	Christian Bleiler
AH	Andreas Hessenthaler
TK	Thomas Klotz
AK	Aaron Krämer
BM	Benjamin Maier
SM	Sergio Morales
MM	Mylena Mordhorst
HS	Harry Saini

Table 1: Initials of people working on examples, in alphabetical order (surnames).

Progress	Initials	Name of example	Dimensions	Equation	Boundary conditions	Mesh type	Interpolation order	Time dependence
x	AH	Example-0001	3D	Laplace	Dirichlet	generated	linear	static
		Example-0002						
		...						

Table 2: Example-0001 to example-0099. Who is doing what? What is finished? See Table 1.

Progress	Initials	Name of example	Dimensions	Equation	Boundary conditions	Mesh type	Interpolation order	Time dependence
x	AH, HS	Example-0101 Example-0102 ...	2D	Linear elasticity	Dirichlet	generated	linear	quasi-static

Table 3: Example-0101 to example-0199. Who is doing what? What is finished? See Table 1.

3 DIFFUSION EQUATION

3.1 Equation in general form

$$\partial_t u + \nabla \cdot \nabla u = f \tag{1}$$

3.2 Example-0001

3.2.1 *Mathematical model*

We solve the following scalar equation,

$$\nabla \cdot \nabla u = 0 \qquad \Omega = [0, 2] \times [0, 1] \times [0, 1], \tag{2}$$

with boundary conditions

$$u = 0 \qquad x = y = z = 0, \tag{3}$$

$$u = 0 \qquad x = 2, y = z = 1. \tag{4}$$

No material parameters to specify.

3.2.2 *Computational model*

- This example uses generated meshes
- Commandline arguments are:
  number of elements in x-direction
  number of elements in y-direction
  number of elements in z-direction
  interpolation order (1: linear; 2: quadratic)
  solver type (0: direct; 1: iterative)
- Commandline arguments for tests are:
  2 1 1 1 0
  4 2 2 1 0
  8 4 4 1 0
  2 1 1 2 0
  4 2 2 2 0
  8 4 4 2 0
  2 1 1 1 1
  4 2 2 1 1
  8 4 4 1 1
  2 1 1 2 1
  4 2 2 2 1
  8 4 4 2 1
- This is a static problem, i.e., the boundary conditions are applied in one step.

3.2.3 *Results*

```
Passed tests: 12 / 12

No failed tests.
```

3.2.4 *Validation*

We use CHeart rev. 6292 to produce numerical reference solutions.

Figure 1: Results, CHeart reference.

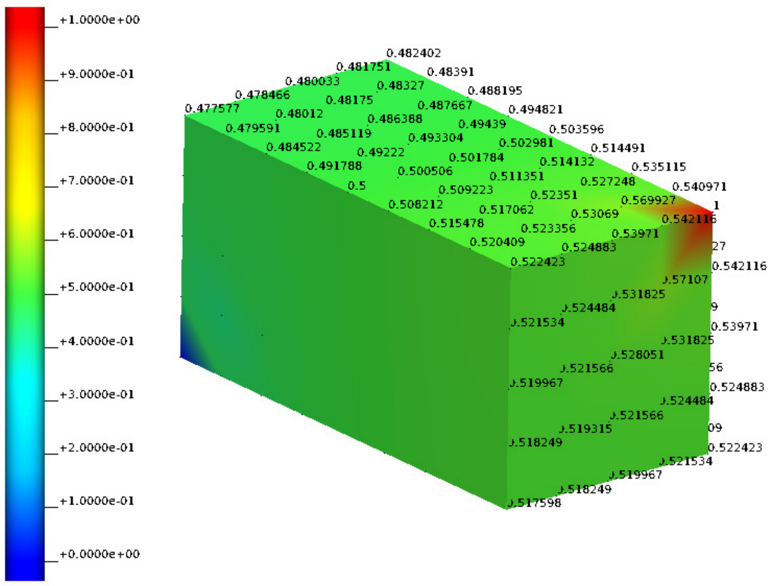

Figure 2: Results, iron reference.

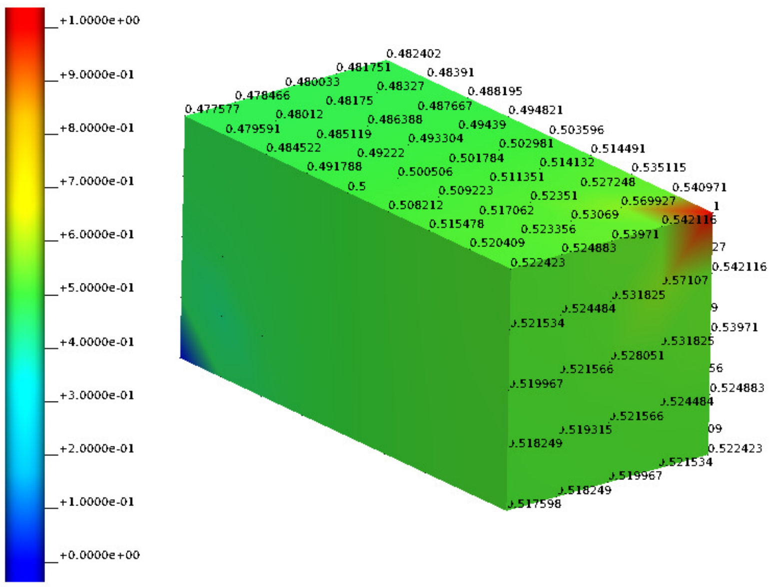

Figure 3: Results, current run.

4 LINEAR ELASTICITY

4.1 Equation in general form

$$\partial_{tt}\mathbf{u} + \nabla \cdot \boldsymbol{\sigma}(\mathbf{u}, t) = \mathbf{f}(\mathbf{u}, t) \tag{5}$$

4.2 Example-0101

4.2.1 *Mathematical model*

We solve the following equation,

$$\nabla \cdot \boldsymbol{\sigma}(\mathbf{u}, t) = 0 \qquad \Omega = [0, 160] \times [0, 120], t \in [0, 5], \tag{6}$$

with time step size $\Delta_t = 1$ and boundary conditions

$$\dots \qquad \dots, \tag{7}$$
$$\dots \qquad \dots. \tag{8}$$

2D: specify thickness, Young's modulus and Poisson's ratio.

4.2.2 *Computational model*

- Length, width, height
- Direct/iterative solver
- Generated/user mesh
- Number of elements
- Interpolation order
- Number of solver steps (time steps, load steps)

4.2.3 *Results*

Figure 4: Results, analytical solution.

4.2.4 *Validation*

CHeart rev. 6328, Abaqus 2017, analytical reference solution, whatever...

Figure 5: Results, Abaqus reference.

Figure 6: Results, iron reference.

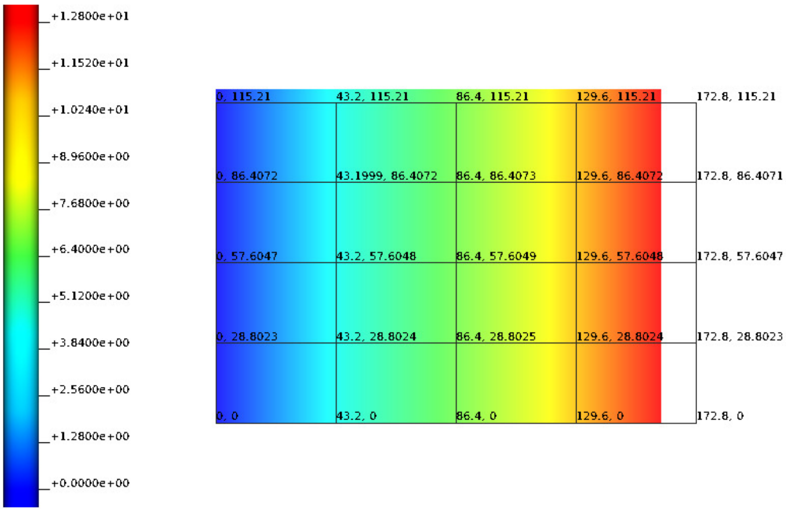

Figure 7: Results, current run.

5 FINITE ELASTICITY

6 NAVIER-STOKES FLOW

7 CELLML MODEL

REFERENCES

[1] Chris Bradley, Andy Bowery, Randall Britten, Vincent Budelmann, Oscar Camara, Richard Christie, Andrew Cookson, Alejandro F Frangi, Thiranja Babarenda Gamage, Thomas Heidlauf, et al. Opencmiss: a multi-physics & multi-scale computational infrastructure for the vph/-physiome project. *Progress in biophysics and molecular biology*, 107(1):32–47, 2011.